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Plankton Production Biology

Karl Banse
University of Washington
School of Oceanography
Box 357940
Seattle, WA 98195-7940
phone: (206) 543-5079 fax: (206) 543-6073 email: banse@ocean.washington.edu

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http://www.ocean.washington.edu

LONG-TERM GOALS

Using existing data I continue to investigate hydrography and nutrients in respect to plankton production in the central and eastern Arabian Sea, on the shelf off India's west coast, as well as in the central Bay of Bengal outside of the EEZs of India and Sri Lanka. Occasionally I comment on general oceanographic or ecological principles.

OBJECTIVES

The principal objectives during FY2012 were comments on the roles of top-down processes for the concentrations, the size composition of phyto-and zooplankton, and the rates of change, and a sketch of a proposal for a nutrient budget for the central Bay of Bengal.

APPROACH

Largely, cost-efficient mining of old and new oceanographic data is used, while keeping old (pre-1980) literature in mind. My personal sustenance for some 15 years has been provided by TIAA-CREF and Social Security, whereas the research expenses are borne by the ONR grant.

WORK COMPLETED

(1) Major overview of the roles of top-down processes in the pelagic domain
A principal goal of biological oceanography of the pelagic domain is to understand the observed distributions of organisms in respect to What, When, Where, and Why. Leaving advection and eddy diffusion aside, the processes comprise growth and reproduction and the rates of change, which for phytoplankton are driven by light, nutrients, and temperature, and for animals by food (so-called bottom-up control). The color satellites show that from day to day chlorophyll changes very little with time in most of the open sea, although the cell division rates tend to about one doubling a day, while blooms are the exceptions. The biomass and species composition and the rates of change depend often or largely, on grazing and predation even in a developing phytoplankton bloom (top-down regulation).

The rate of change of phytoplankton concentration is far smaller than that inferred from the rates of carbon ^{14}C uptake or cell-division, or estimated from remotely determined chlorophyll, or calculated

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by global ecosystem models. The rate of concentration change may not even have the same sign as the two former rates (Fig. 1) because of the top-down effects of grazing and predation mortality. Mortality, however, is very difficult to estimate accurately, leave alone to measure. The zooplankton rate processes are the big challenge.

In the second half of my review (Banse, 2013) I have once again noted the lack of recognition of the top-down regulation in marine biogeochemical work, as holds also for terrestrial ecology (cf. Banse, 2007). Overall, the review presents skeptical, if not pessimistic opinions of the state of the field (see Results, below).

(2) The central Bay of Bengal as an estuary—why is there next to no surface nitrate in spite of much entrainment from below?

As a whole the Bay of Bengal, to the east of the Indian Peninsula, functions as an estuary driven by the large sum of river runoff plus precipitation minus evaporation. Low-salinity water with next to no nitrate (32.5 to 34.5 psu, 0.1 up to perhaps 0.3 µM NO_3^-) leaves at the surface, while high-salinity, high-nitrate water (35.0 psu, 30-40 µM NO_3^-) enters at depth and is entrained into the upper layers. The nutrient contributions by rivers and the atmosphere appear to be relatively small (e.g., Rao et al., 1994; Sanjeev Kumar et al., 2004), and so the settling POC is principally of marine origin (Unger et al., 2005). Nitrogen is the principal nutrient element limiting primary production and, hence, affecting the flux of POC into the deeper layers.

As a numerical example for the huge entrainment, the upper-layer average salinity of 32.5 is maintained by mixing of one volume of freshwater with 13 volumes of 35.0 psu water (32.5 divided by [35.0 – 32.5 = 2.5]). This will transport about 27-37 µM NO_3^- from depth into each liter of the surface layer. The "dilution ratio" is even larger than 13 when considering a seasonal surface salinity of, say, 33.5. Yet, year-round we observe near-zero NO_3^- above the pycnocline except sometimes during winter in the north and in the cyclonic eddies fairly common in the west when they penetrate into the mixed layer. The levels of ^{14}C uptake by phytoplankton and of chlorophyll in the central Bay are significantly lower than in the offshore Arabian Sea (Prasanna Kumar et al., 2010), which fact is largely attributed to the different atmosphere-ocean interactions and the resulting stratification. Yet, years of deployment of particle interceptor traps at around 1 km depth yielded about the same, quite high fluxes of POC in both central basins (Unger et al., 2003, Stoll et al., 2007).

Regardless of the mechanism transporting the NO_3^- upward, only the salt remains above the pycnocline. What happens to the entrained NO_3^-? Aside from the transitory blooms caused by eddies and their disposition, is the principal sink the Deep Chlorophyll Maximum (DCM) in the pycnocline, which traps the NO_3^- moving upward in the entrained water (cf. Fig. 2)? Does the DCM thus cause the unusually average high f-ratio and export ratio of particulate organic matter of ~0.5, as well as the Bay to be a CO_2 sink? In principle, non-transient DCMs are maintained by the difference between the rates of phytoplankton cell division and losses and can thus be studied anywhere. In the Bay, however, the vertical flux of NO_3^- can be determined via the salinity rather than from the necessarily imprecise physical estimates of eddy diffusion and vertical advection. Moreover, the NO_3^- concentrations at depth are much higher than in most other seas and should yield high flux signals.

To answer the questions, a large integrated research program might be considered, which attempts a nitrogen budget of the central Bay of Bengal as an estuary. The central region, between about 8° and 15°N and 85° and 88°E, is outside the Exclusive Economic Zones (EEZs) of India and Sri Lanka and thus not affected by the rules governing research inside of them. If at first only the DCM were to be

studied, the essence would be to compare the upward flux of NO_3^- through the pycnocline, as determined from the salt balance, with the measured NO_3^- uptake in the DCM over suitable time scales. To motivate the addressing of the issue(s) I have sent 11 single-spaced pages, plus many figures, of a revised Memo to the Scientific Steering Committee of the IMBER-approved SIBER [**S**ustained **I**ndian **O**cean **B**iogeochemistry and **E**cosystem **R**esearch]), to a few other organizations around the Bay of Bengal, and to several individuals, inviting them to pursue these ideas. The Memo also summarizes needed measurements.

Note that a pronounced oxygen minimum zone is present in the lower mesopelagic zone of the Bay, which is almost as deprived of O_2 as the one in the central Arabian Sea. The maintenance of the two minima is of global biogeochemical importance because of denitrification (not yet occurring in the Bay), but the balance of advection and consumption of O_2 is not understood quantitatively. First in my view, rigorous water (salt) budgets are required in both basins.

RESULTS

The principal conclusion in my forthcoming review (Banse, 2013) is a pessimistic judgment on major aspects of the current mechanistic understanding of the dynamics of the euphotic zone and the flux of particulate organic carbon (POC) into the mesopelagic ("twilight") domain below. On p. 13 I state, "The inability to determine phytoplankton mortality—and, beyond that, the inability to 'see' the zooplankton remotely—is the fundamental handicap of satellite-based estimates of the dynamics of primary production". Moreover, at present we have little hope for predicting accurately from environmental data for particular situations what percentage of phytoplankton production will not leave the euphotic zone because of being re-mineralized within it. For estimating vertical POC flux with an accuracy useful for mesopelagic carbon budgets (by implication, of C flux to greater depth), I state (p. 15), "An [in situ-based] prediction for organic flux based on, say, 80%–90% of phytoplankton net production is remineralized in the epipelagic layer" would for the mesopelagic denizens mean 20% or 10% of net production being made available. This is a twofold range of supply of organic matter! A range of 85%–95% would translate into a threefold range. I fear that neither of the two predictions with such narrow confidence limits is presently attainable except perhaps for single, well-investigated stations. How are the students of the twilight zone and the deep sea at large to live with that degree of uncertainty?

TRANSITIONS

*(1) **The central Bay of Bengal as an estuary***
The Memo under item (2) of the first section suggests a major integrated attempt for a nitrogen budget in the central Bay of Bengal, outside the EEZs of India and Sri Lanka. Note that the principal processes around the Deep Chlorophyll Maximum (DCM) apply to all non-transient DCMs including those forming in summer in large temperate lakes, but that of the Bay is predestined for a profound investigation as indicated under item (2), except that it is not as easily accessed as that of a lake.

*(2) **Printing of a translated Russian monograph on copepod larvae (nauplii)***
To help in opening windows to the little-known Russian-language oceanographic literature, ONR in some of my earlier grants had supported translations of five monographs and the commission of a new book in English about the last integrated Ukrainian expedition to the northern Arabian Sea in 1990. The financial and logistic problems of editing and printing led to very long delays, as reported previously. Together with Senior Lecturer Dr. Andrew G. Hirst of the Queen Mary University in

London, during FY2011 the editing of a fourth monograph, by Sazhina (1985), was largely completed. Currently we are preparing the book for printing by the Indian Academy of Sciences in Bangalore and India's National Institute of Oceanography in Dona Paula, Goa.

The monograph provides illustrated keys for identifying the six stages of the nauplii (copepod larvae) of 85 common species from the Atlantic with its adjacent seas, the eastern tropical Pacific, and the warm parts of the Indian Ocean. It is the first and after 27 years still by far the most comprehensive key of its kind but largely unknown outside the Russian-speaking world. To our knowledge there are two copies of the original version in the U.S. library system. Our recent inquiry via the mailbox of OCB (Ocean Carbon and Biogeochemistry, an international program dominated by physical and chemical oceanographers) at Woods Hole Oceanographic Institution, MA, about the interest in a free distribution elicited 91 requests in three weeks, almost entirely by individuals rather than libraries.

IMPACTS and IMPLICATIONS

1. Much of my review (Banse, 2013) once again bemoans the prevailing neglect of the top-down processes in foodwebs—all species are growing, but few researchers and models provide for the all-present death. The drastic differences in phytoplankton biomass, net production, and net community production in a global model using 78 phytoplankton types and contrasting high vs. low maximal specific grazing rates combined with or without food preferences (switching) are illustrated by Prowe et al. (2012: figs. 5-7).

2. The memo about the Bay of Bengal addresses scientists of the countries bordering the Bay, as well as American and European colleagues. Open-sea work in the Arabian Sea, including research about the processes in the O_2 minimum zone, is practically at a stand-still because of the Somalian pirates and the resulting high insurance premiums for ships. It is to be seen whether my message about the Bay will be picked up.

3. The translation and distribution of Sazhina's keys will permit the study of stage-specific population dynamics (growth rate, production, mortality) of copepod larvae (nauplii) in mixed populations in the field or captured water columns (mesocosms). Since biology proceeds through species rather than carbon and chlorophyll, the work, once available, will be invaluable.

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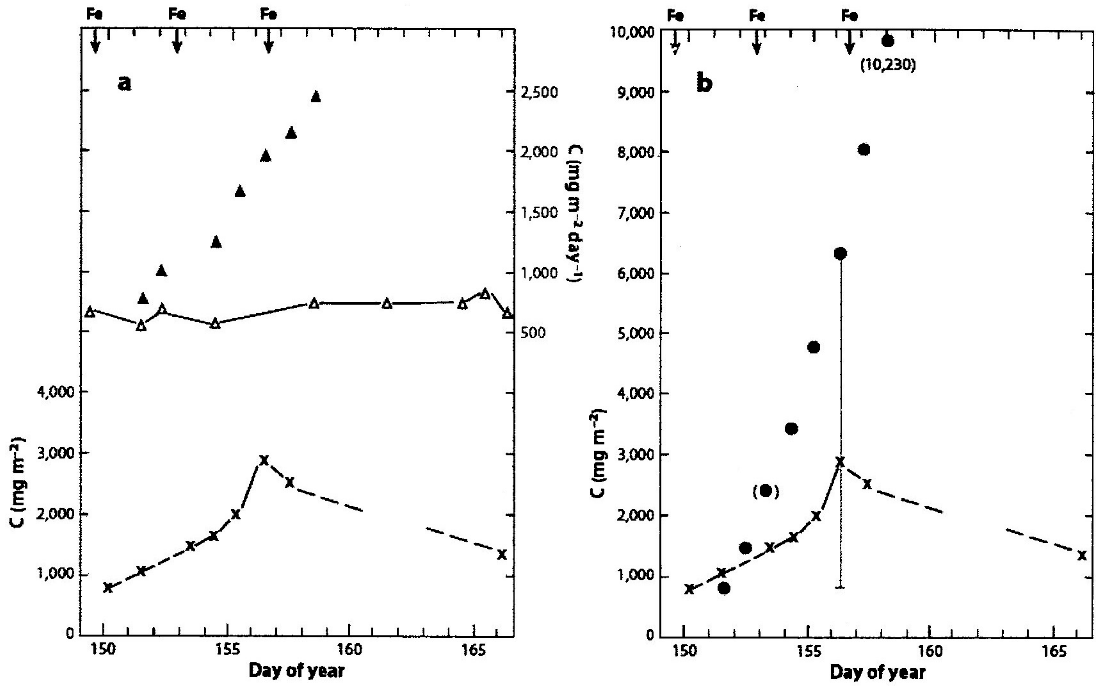

Fig. 1. Photosynthetic carbon uptake and grazing losses during the iron fertilization experiment IronEx II west of the Galapagos Island, integrated for the euphotic zone and corrected for physical dilution of the fertilized patch. Days on bottom for 1995; arrows on top, dates of iron additions. (a) Upper part, simulated in situ ^{14}C uptake outside and inside the patch (open and filled triangles, respectively). Lower part, carbon concentrations, with concentrations for days 150–154 estimated from 15-m values. (b) Cumulative carbon uptake, corrected for 13% daily losses from mixing, and carbon concentration (from [a]); vertical bar indicates the uptake since day 151, principally lost by the measured grazing; parentheses signify an uncertain value. Adapted from Banse (2013).

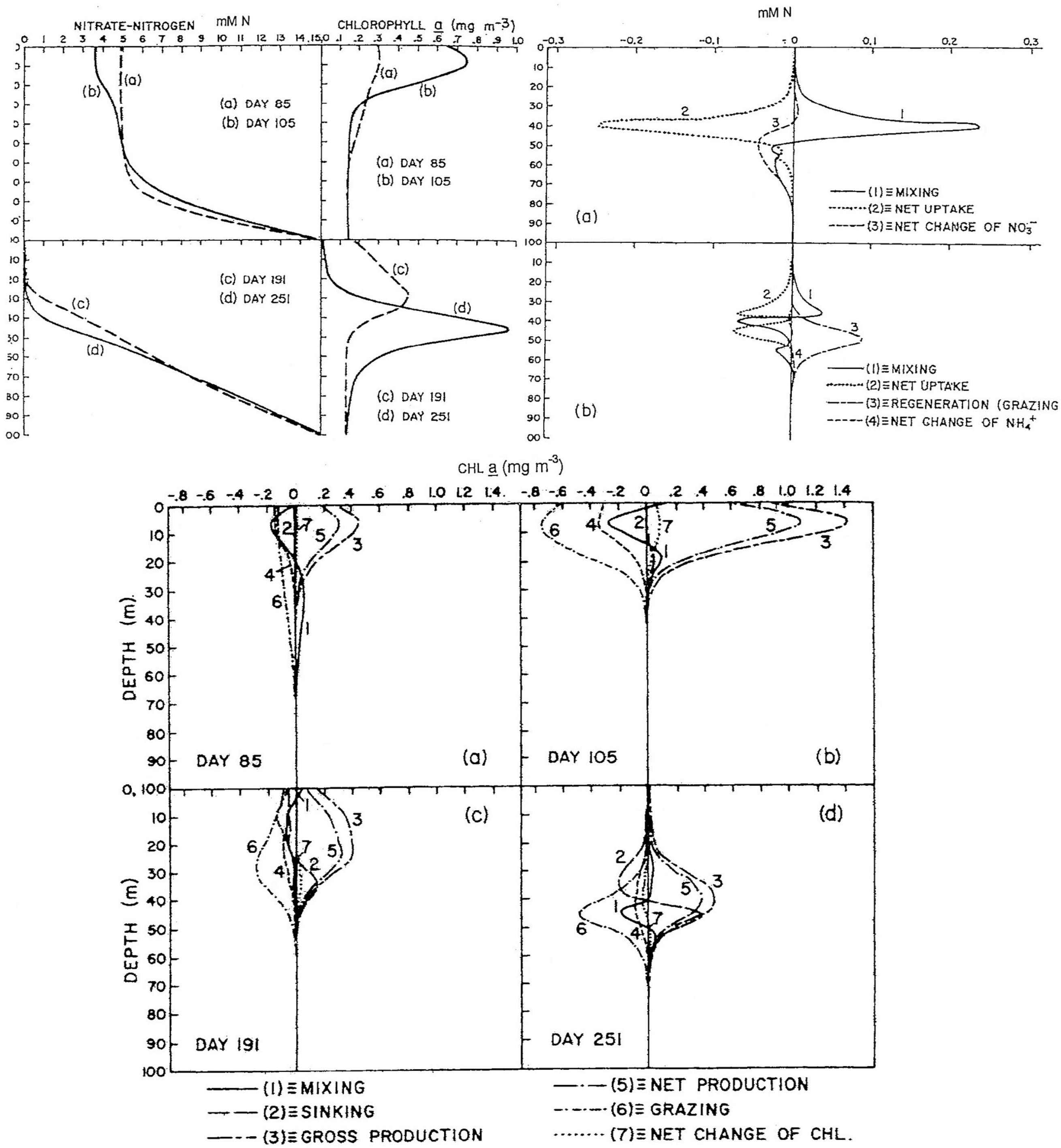

Fig. 2. Four dates in a seasonal phytoplankton production model of a cool-temperate ocean with depth dependence of nitrate and chlorophyll; the seasonal change to vertical column stability occurred on Day 96 (upper left); terms of the chlorophyll equation integrated over 48 h, with the grazing rate [6] being the difference between the rates of net production [5] and net change of chlorophyll [7] (bottom); and the 48-h balance from the NO_3^- and NH_4^+ equations for day 251 (upper right) (from Jamart et al., 1977).